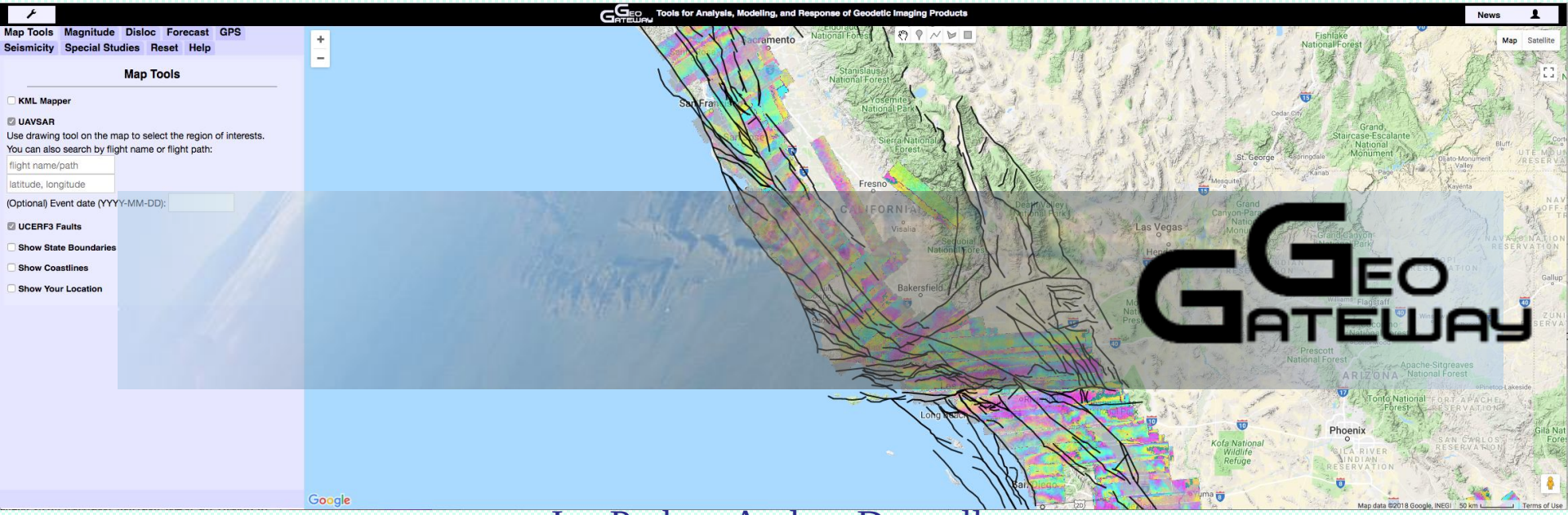
Displaying Multiple Data Types in the GeoGateway Public Mapping System

Including a System for Rapid Surface Fracture Detection in Raw and Unwrapped Radar Interferograms



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With thanks to NASA programs:

Advanced Information Systems Technologies, Earth Surface and Interior

Applications of Geodetic Imaging, Decision Support Through Earth Science Research Results

Topics

- Background: Measuring deformation, fault network slip.
- Components of GeoGateway maps.
- Useful combinations for investigating seismic events
- Measuring slip from raw interferograms (complex conjuage)
- Gradients (slip) from areas that didn’t unwrap:
  - Brawley
  - Napa

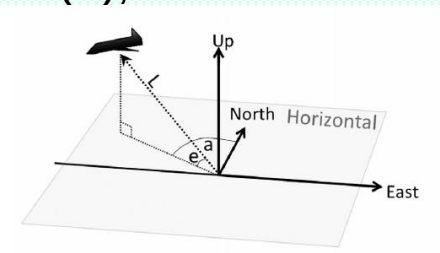
Measuring slip:
first, measure fine-resolution deformation.

UAVSAR Pod On Gulfstream III:

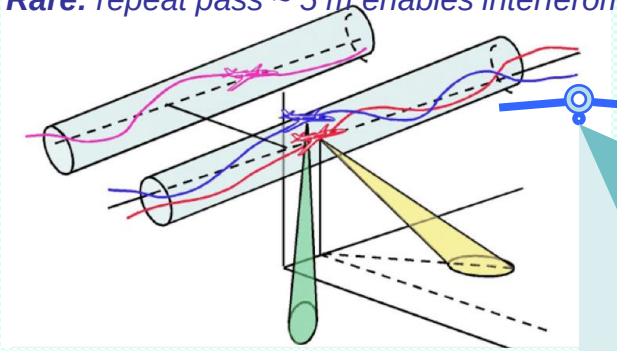
Gulfstream 3 semi-piloted aircraft

- Radar for studying earth processes
- **Repeat visit→ landscape *change* image**
- Fine-resolution: 7 m pixel size:
- >120 Megapixel images
- Sensitive: sees <1 cm surface fault slip
- For true strike slip D = 100mm, reduce by $D_{LOS} = D \cos(a - s) \cos(e)$, ~50 mm

One day on Global Hawk or other drone?



Rare: *repeat pass ~ 5 m enables interferometry)*



UAVSAR looks to the side about 20 to 70 degrees: Elevation angle "e"

Repeat Pass Interferometry:

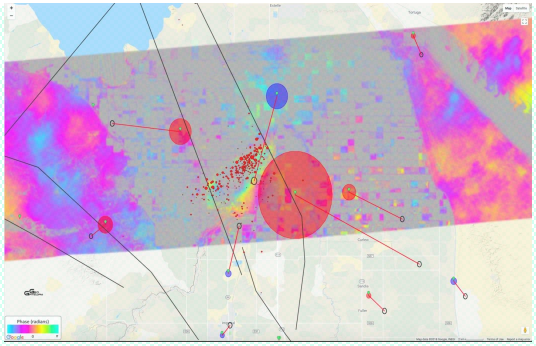
- Surface deformation, mapped into
- Elevation Φ_{el}, azimuth θ_{Az} (Line-Of-Sight)

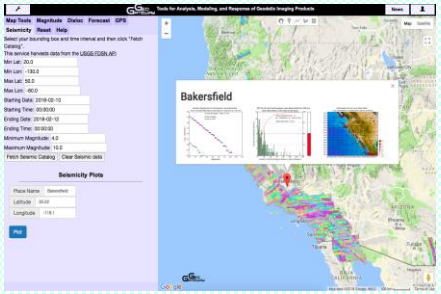
$S_{Proj} = S \cos(\Phi_{el}) \cos(\theta_{Az} - \theta_{Strike})$

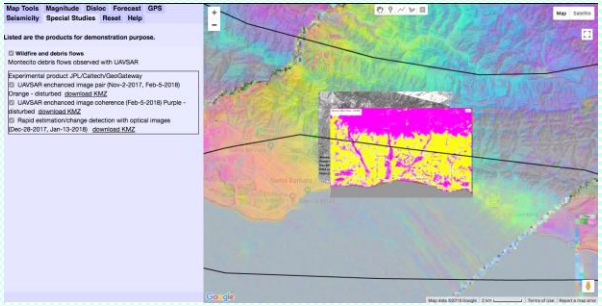
- **Herein, "Slip" refers to this projected slip S_{Proj}**

GeoGateway map products

- UAVSAR
- GNSS time series, products
- Seismicity
- Scaling relations (GR-filling)
- UCERF-3 faults (California)
- *Any kmz overlay*
- Sentinel 1 InSAR (experimental)
- Polarimetry-derived products (experimental)
- User location
- User location
- (notecards, ratings)



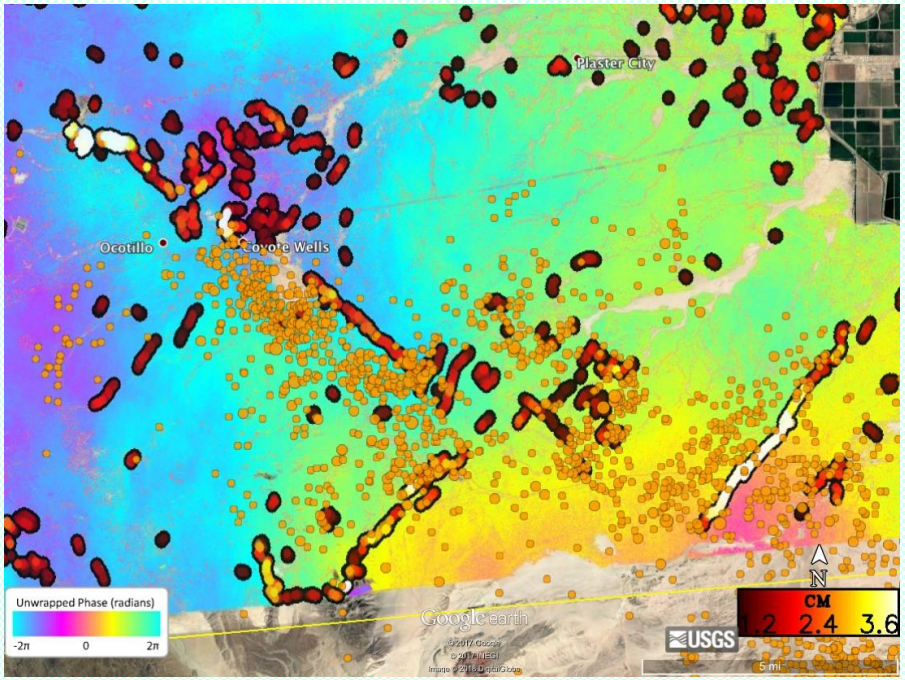




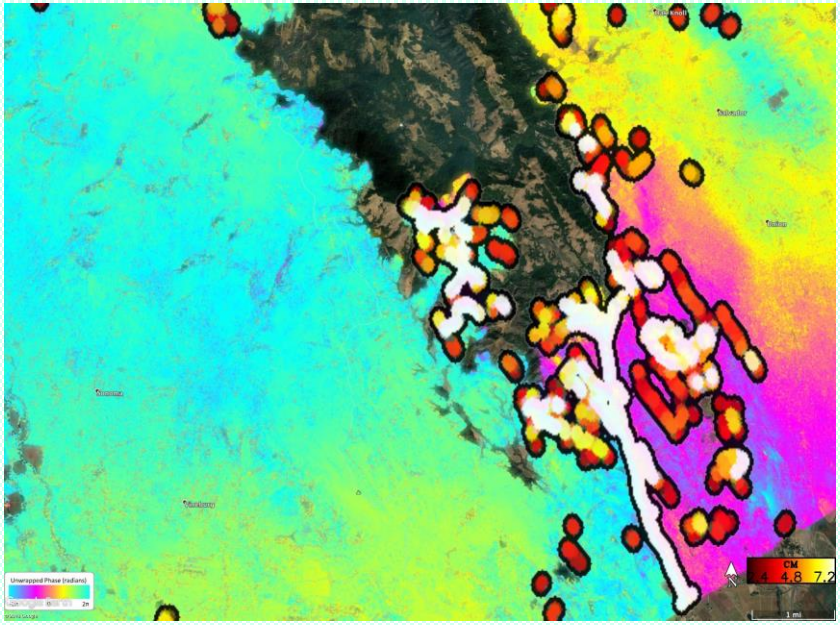
GeoGateway map products

- Overlaying products:

El Mayor Cucahpah, 2010; coseismic + June aftershocks Interferogram, slip, seismicity



South Napa 2014; coseismic Interferogram, slip

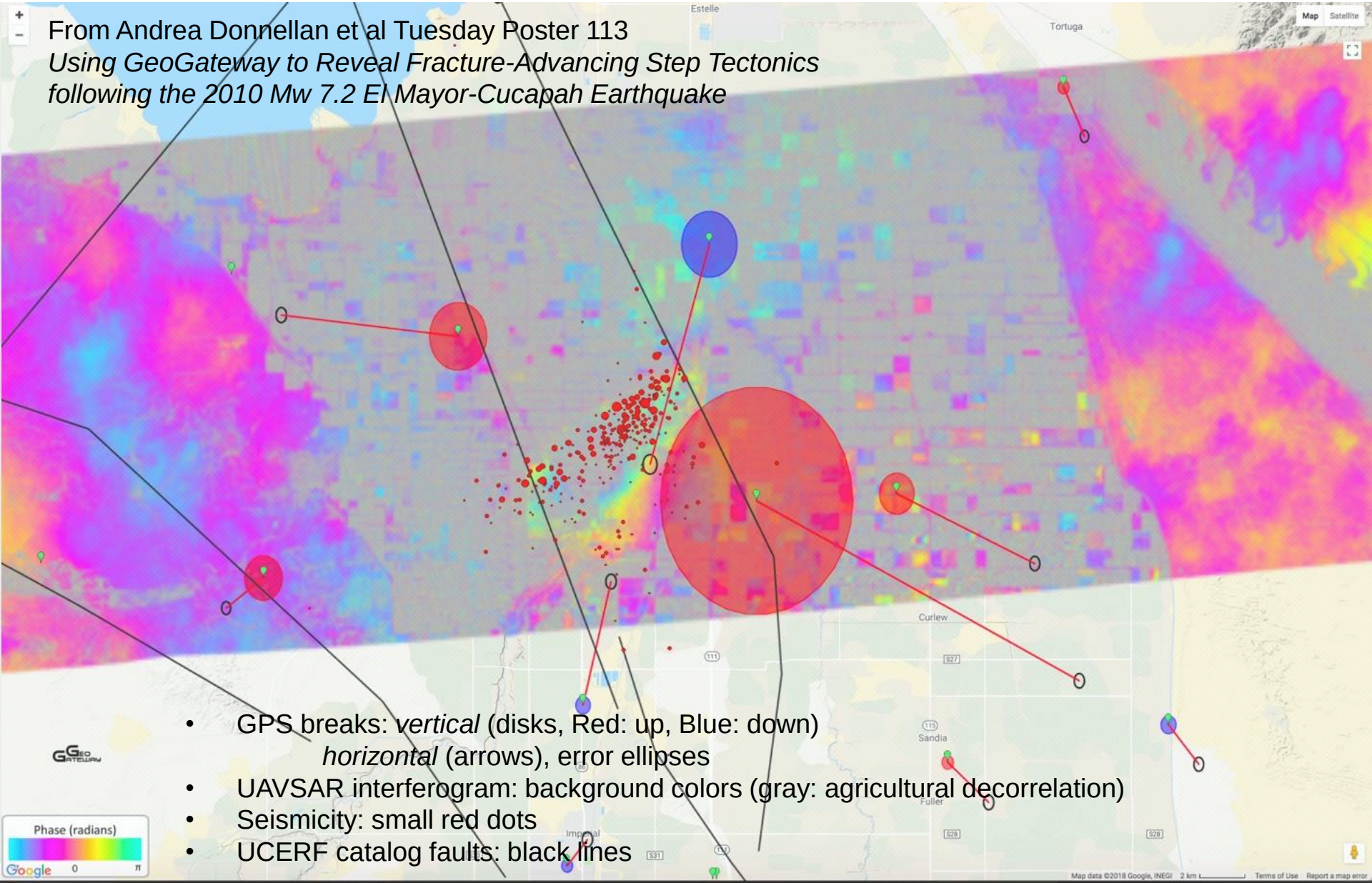


Phase unwrapping failure creates a hole.

Overlaying GeoGateway map products

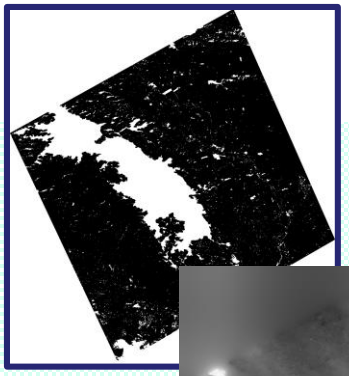
Brawley Swarm 2012: UAVSAR, GPS, Seismicity, Faults

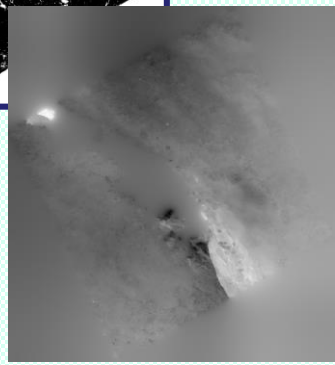
From Andrea Donnellan et al Tuesday Poster 113
Using GeoGateway to Reveal Fracture-Advancing Step Tectonics following the 2010 Mw 7.2 El Mayor-Cucapah Earthquake

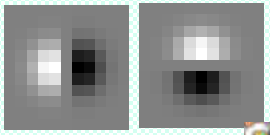


- GPS breaks: *vertical* (disks, Red: up, Blue: down)
  horizontal (arrows), error ellipses
- UAVSAR interferogram: background colors (gray: agricultural decorrelation)
- Seismicity: small red dots
- UCERF catalog faults: black lines

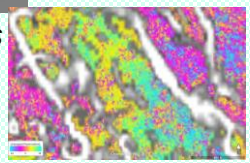
Surface Fracture Process



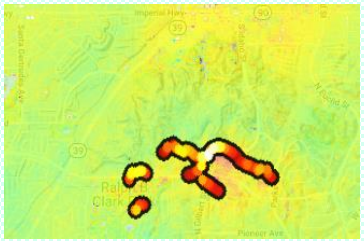




Gradient operators

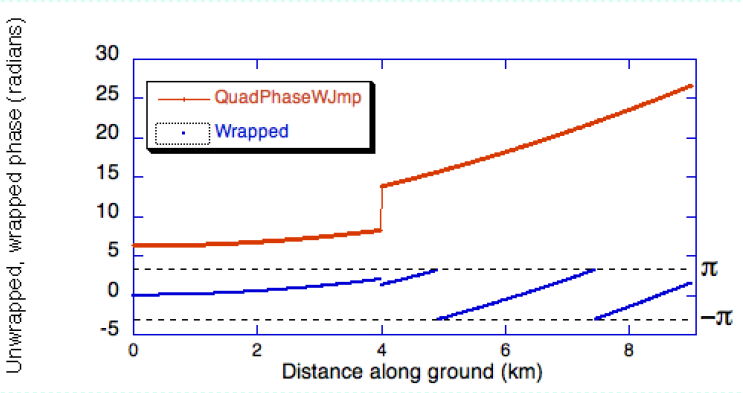


- 0) Identify bad pixels; fill with smooth phase values (no jumps). **0alt) Complex**: treat values, not phase
- 1) Canny detection: MaxGradient, deduplication, connection bias (hysteresis)
- **1alt) Complex**->phase gradient (diff) /_ L R*
- 2) Sense of slip: **G**x**L**
- 3) Fit sigmoids (S,W) to close local cross sections **3alt) Complex***:* Fit sigmoid differences to /_ C0 Cn*
- 4) Generate “worm plots”, fracture tables:



Phase gradient for raw interferograms

- A raw interferogram is a complex-valued array of georeferenced samples.
- Complex angle is phase, ~deformation, but cycles within –pi to pi.
- Phase unwrapping removes these jumps, but often fails, leaving holes or worse.
- Direct difference-based gradients on complex angle: large spurious contours
- Instead of angle difference, use angle of conjugate product
- Shown: 173 day EMC UAVSAR interferogram phase (complex interferogram angle), color; and
- Grayscale overlay magnitude of gradient computed three ways



Gradient of unwrapped phase:

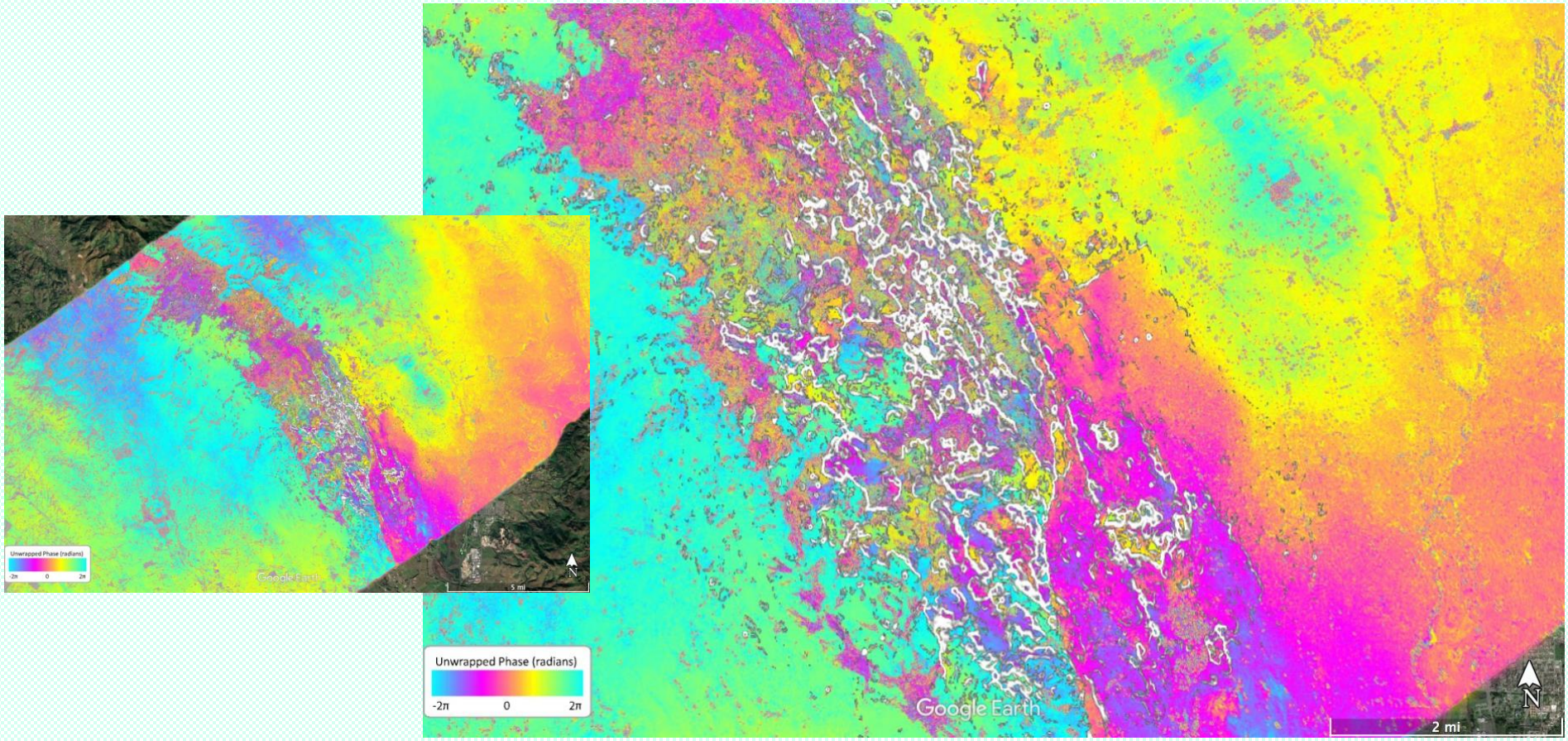
YUHA FAULT

Gradient of complex angle:

Angle of unwrapped product: CYCLE JUMP

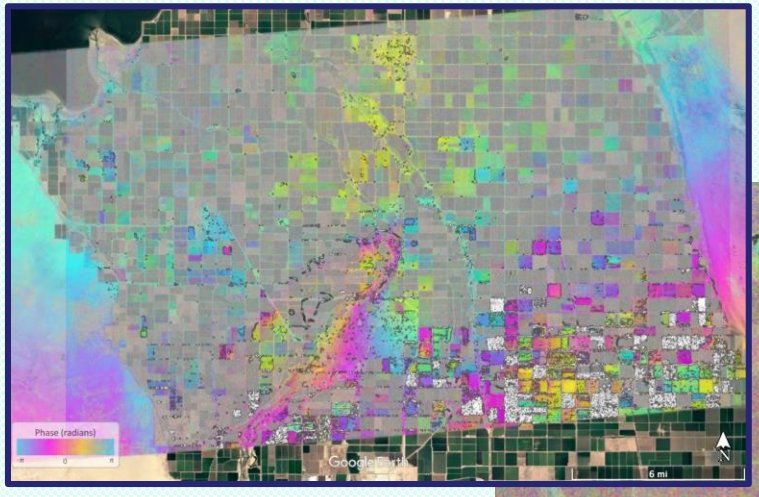
Magnitude Phase Gradient, Conjugate Product

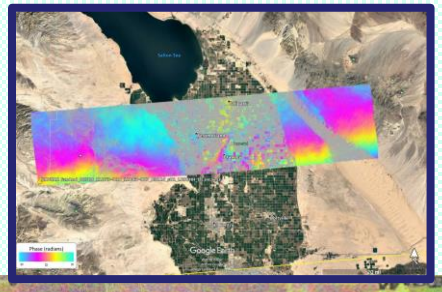
- Napa (spans quake)

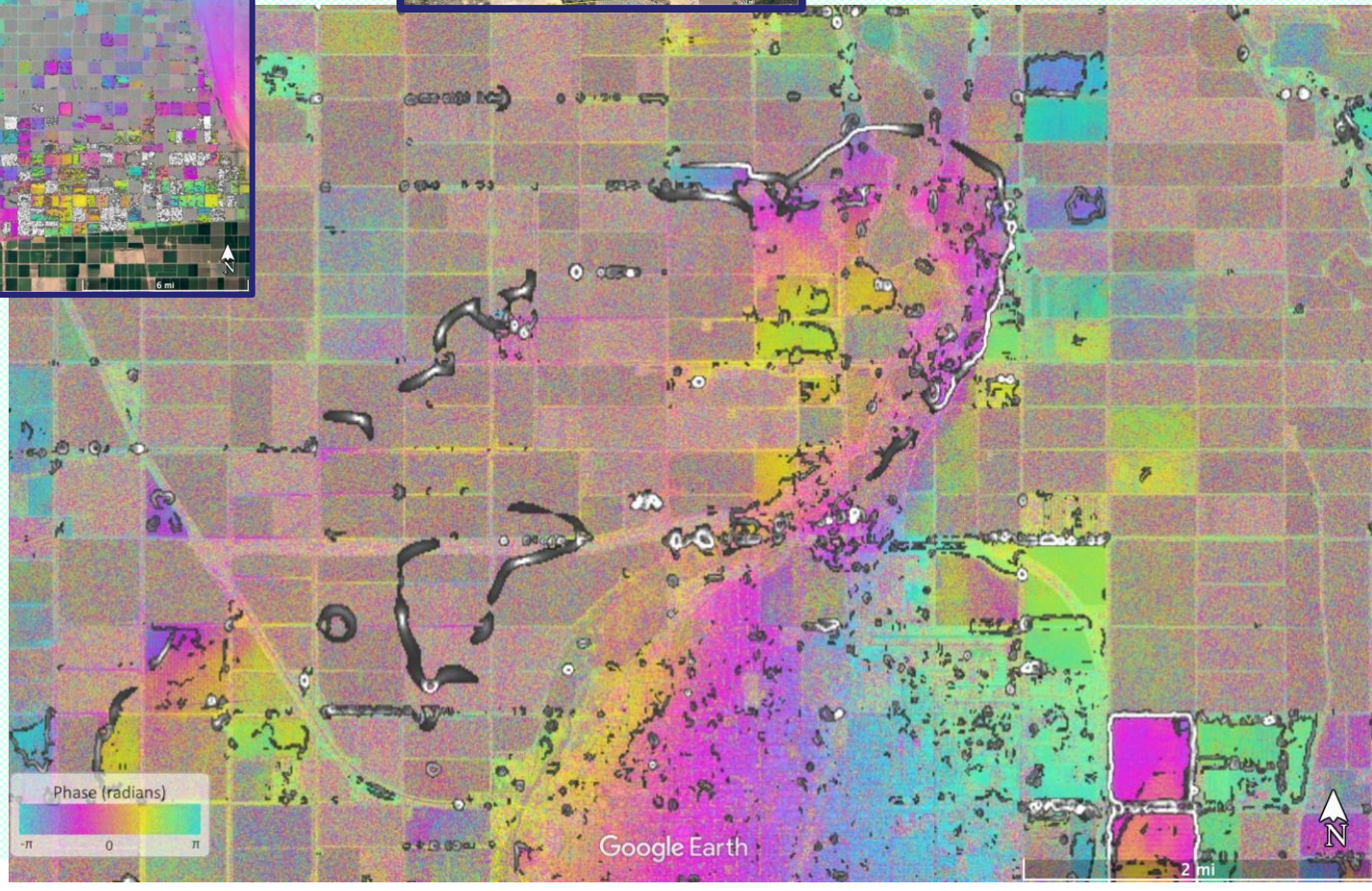


Magnitude Phase Gradient, Conjugate Product

- Brawley (spans swarm)







Next Steps, Conclusions

Next Steps

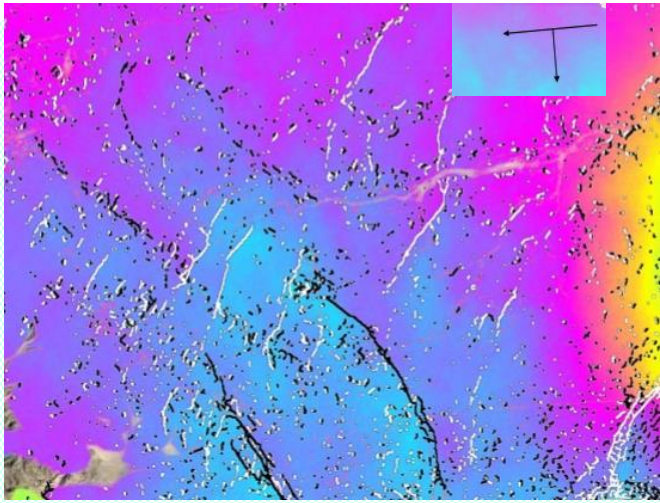
- Tablulate slip parameters for raw interferograms.
- Fully integrate into GeoGateway.

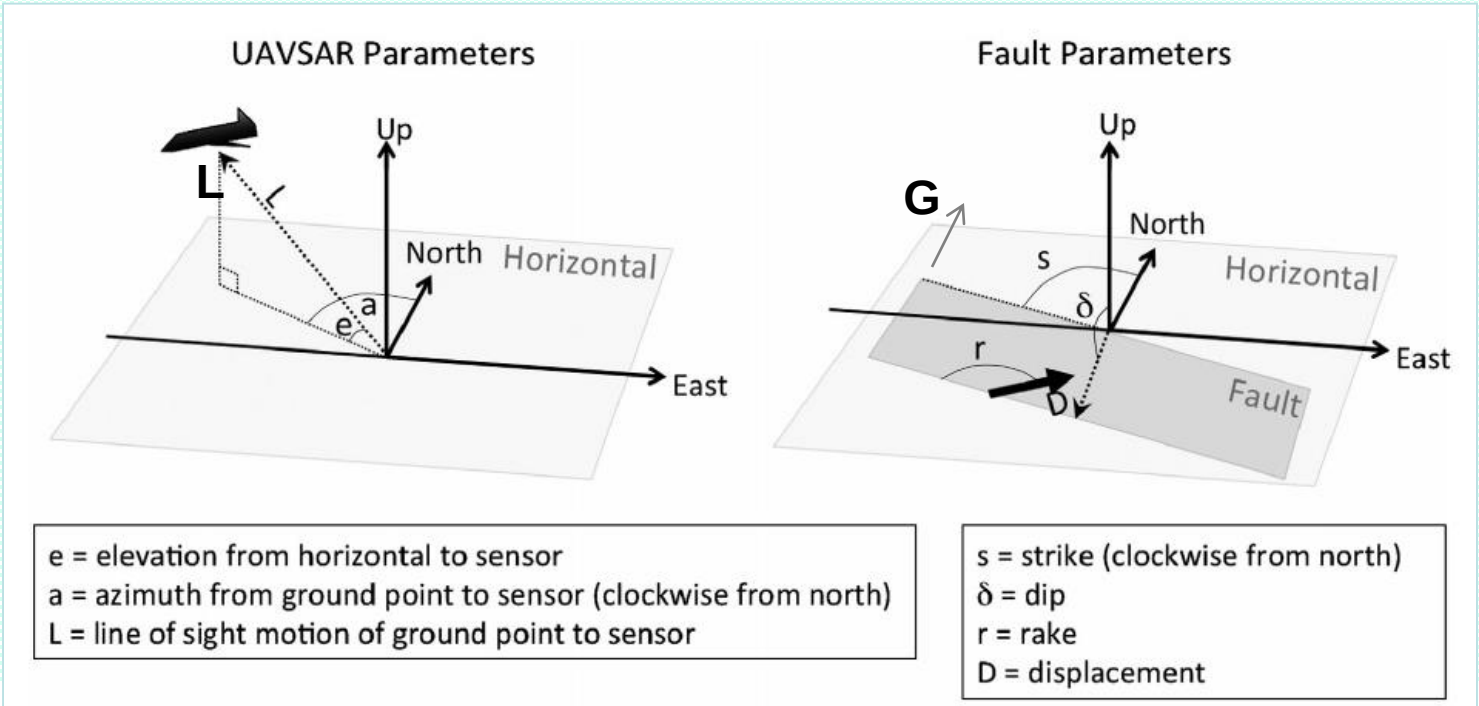
Conclusions

- With KML tool and seismicity overlay, GeoGateway provides publication-quality images.
- Raw interferogram slip extraction from conjugate product
- Complex method roughly doubles areas of interest.

PseudoMechanism: Ocotillo

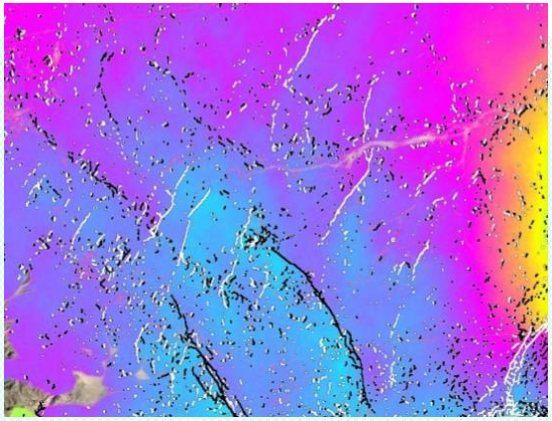
- Radar sees rupture as a value jump across a line
- One side moves closer, one side farther
- Gradient **G** direction shows which moved closer
- Sign of **G** x **L:**
  - + white pseudo left lateral (pLL)
  - - **black** pseudo right lateral (pRL)
  - (*but could have vertical part*)



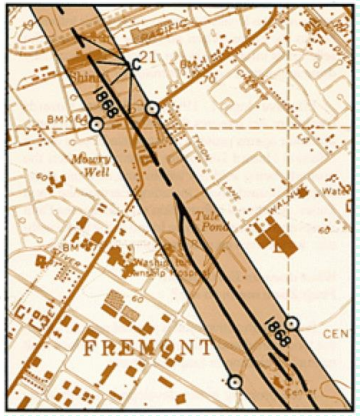


Why map secondary faults?

- Science:
  - strain partitioning
  - tectonic fabric
  - (width) field survey “miss”



- Society:`
  - Safety - conform to Alquist-Priolo laws
  - Hazard to man-made structures:
    - Dams
    - Pipelines
    - Roads, runways
    - Buildings
    - Bridges
    - Aqueducts
    - Industrial fuel tank farms



http://www.conservation.ca.gov/cgs

How to automatically map: width, slip: from Napa sample

- Gradient across fault
- Simulated (Okada elastic half-space)
- Varying fault top (locked above this), 0-500m for dx = 200m
- Sum across width -> consistent total slip
- Width: how? Currently by slope ratio threshold (left)